(71) Central Research Institute for Transport, Center for Process Automation, Merkgrafendamm 24, Berlin, 1017, DD

(54) Method for the energy-saving control of rail-bound means of transportation which travel in succession

(55) Method, energy-optimization, control, rail-bound means of transportation, succession, delay, time of succession of trains, time measurement, counting backward, travel time margin, travel strategy, aiming at punctuality

(57) The invention relates to a method for the energy-saving control of rail-bound means of transportation which travel in succession, each means of transportation being individually controlled in an optimum way with respect to energy. The invention can be applied primarily in transport systems with a dense succession of individual, similar means of transport. When a means of transport is delayed, data on the remaining time difference up to the expiry of the decisive time of succession of trains is transmitted to the following means of transportation by a backward-counting time measuring operation being activated by a traffic means which leaves a stop, the starting value of which time measuring operation corresponding to the decisive time of succession of a train which is valid for the route section ahead and stopping at the moment when the next means of transportation moves off and thus indicating the time supplement which is evaluated additively with respect to the travel time margin in order to determine a new travel strategy with optimum energy consumption, the means of transportation aiming at punctuality as it travels, in the same way as the means of transportation traveling ahead.

Field of application of the invention

The invention relates to a method for the energy-saving control of rail-bound means of transportation in which the effects reflecting from the succession of the individual means of transportation due to delay of the vehicle traveling ahead are taken into account.

Said method can be applied primarily in transport systems which are characterized by a dense succession of the individual means of transportation which are essentially identical in their parameters.

Characteristics of the known technical solutions

A method for the energy-saving operation of local transport (DD B 60 L 15/20, No. 129761) which is obtained in that precalculation and preprogramming operations are carried out as a function of speed when it is necessary to switch over from acceleration to coasting when there are long travel time margins, as a function of travel when it is necessary to switch over from normal travel to coasting when there are short travel time margins and the respectively associated time of application of the brakes is precalculated and preprogrammed as a function of travel on the condition that the timetable is complied with, with the result that, when the switching rule is obeyed, deviations from the schedule which are unavoidable but sufficiently short are compensated. These switching-over commands are to be made available by the control device before or at the time of the start of travel, a location-dependent (fixed-time travel program selection) having to be implemented for predefined constant times during which a vehicle stops at each station and a time-dependent and location-dependent program selection (time-variable program selection) having to be implemented for variable times during which a vehicle stops at a station. The sequence of

switching operations is dependent on the travel modes known in local transport, so that the four modes of control

- downhill travel
- normal travel at maximum speed where appropriate
- coasting
- braking

are necessarily to be carried out in succession.

Whereas in the case of a fixed-time travel program selection the number or address corresponds to a memory location with a predefined bit number, when there is a time-dependent travel program selection there is a direct relationship between the current discrete processing period and a memory location address at which the current travel mode is stored. The respective memory location address for the current travel mode is determined by summing the route sections traveled through or summing discrete time intervals which are characteristic of the processing period. The memory arrangement constitutes here a combination of a plurality of memory circuits which are connected in parallel in address terms. In this way it becomes possible, with relatively low expenditure on control and logic, to achieve the information length required for the digital representation of the switch-off speed V_{abs} of the switch-off travel S_{ab} and of the time of application of the brakes S_{br}.

As a result of the continuing processing period, a travel mode is made available to each time interval by means of an address counter and the memory arrangement when there is a time-dependent travel program selection, an information bit being output by the memory arrangement once per route section when a maximum starting time or a maximum number of time intervals is exceeded, so that when this output time information is summed the uniquely defined assignment

is obtained between the continuing processing time and the travel mode which is valid for a travel section.

The respective current travel mode is transferred into a buffer using a start key and made available for further processing. Travel modes which are not required are gated out. The method described has the disadvantage that a control strategy is predefined which results in a higher energy consumption than necessary if the recommended travel strategy cannot be implemented owing to a delay of the means of transportation traveling ahead. As a result, on the one hand the recommended travel strategy is [lacuna] than the one which can be implemented by safety equipment and on the other hand the necessity for re-starting results in a further additional expenditure of energy.

In addition, it is known that rail vehicles can be controlled in an optimum way with respect to energy (DD B 60L 15/20, No. 208324) by determining in advance the functional relationships for the switch-off points V_{AB}, S_{AB} and S_D and the travel time t_F on the basis of discrete travel times and thus for discrete travel strategies by means of a digital simulation of train journeys corresponding to the real route conditions such as the distance between stops, the gradient of the route, speed profile of the route and the real train and vehicle conditions such as resistance to forward motion, speed/traction force characteristic, mass of train and braking deceleration to a stationary EDVA.

These functional relationships $V_{AB} = \int(t_p)$, $s_{AB} = \int(t_F)$ and a [illegible] $= \int(t_F)$ can thus initially be described by discrete interpolation nodes.

For simplified conditions it is thus, under certain circumstances, expedient to represent the functions $v_{AB} = \int(t_F)$, $S_{AB} = \int(t_p)$, $s_B(t_F)$ by means of a piece-by-piece linearization and the values v_{AB} (t_F), $s_{AB}(t_F)$ or $s_B(t_F)$

which are sought for any travel time predefined values are to be determined by linear equations, linear interpolation relationships or the like. By means of a suitable number of interpolation nodes it is possible to keep the errors caused by linearization within acceptable limits. The on-board electronics to be installed on the vehicle thus have the primary functions of storing the interpolation nodes v_{AB}, s_{AB} and s_B and I_F and processing the necessary sets of rules. The respective storage location address for interpolation nodes which are associated with the current route section is obtained by summing the route sections traveled through in a section counter and also stored sets of rules using the current counter reading in the section counter. The values v_{AB}, s_{AB} and s_B are stored by means of one or more storage words composed of eight bits. The optimum switch-over points v_{AB}, s_{AB} and s_B which are determined as a function of the current travel time predefined value can either be output to the driver of the vehicle, who carries out the actual train control (open-loop control), or transmit via a digital display device, directly to an automatic control device (closed-loop control), so that the driver of the locomotive essentially carries out only a monitoring function using the display device. The remarkable characteristic of the method on the basis of the processing of concrete interpolation nodes is that both switch-off speeds and switch-off travel can be calculated by a mathematical rule and by means of a set of interpolation nodes per route section. The result of the interpretation, and thus the type of travel mode recommended results here directly from the monotonous behavior of the sequence of interpolation nodes stored for each route section.

If the n function words of the interpolation nodes with the numerical index of $j = 1$ to $j = n$ result in a monotonously decreasing sequence in the strict sense, each of the interpolation nodes, and thus the

calculation result, is to be interpreted as a switch-off speed. If the function value of the j - n interpolation node deviates from this monotony, a switch-off speed is represented by it, while the other n-1 function values are identified as switch-off travel values. If the available travel time lies in the region of interpolation nodes j = n-1 and j = n, the j = (n = 1th (travel) - interpolation node is exchanged with the permissible maximum speed dependent on the route or vehicle, which can be determined from the value of the j = nth interpolation node by means of agreed mathematical relationships or simple specifications. The function value of the j-nth interpolation node must always have a greater absolute value than the j = (n-1)th interpolation node in order to be detected as a speed. This precondition is reconcilable with the practical conditions given a suitable numerical representation.

This configuration of the method does not eliminate its described deficiency.

A further method for reducing the technical and financial expenditure for an automated and energy-saving train control system consists in timetable information, route information and train-specific information and ordering terms, which are compressed as key information for all relevant journeys, being entered into the train journey magazine.

For each relevant train number there is a connection box. It contains the respective transport days for the journey with corresponding departure time at the starting point and an indicator to the places in the train journey magazine at which associated strategic information relating to the timetable and the travel strategy can be found. The arrangement of all the connection blocks in succession in the magazine

produces the connection block series. During the preparation of the journey, [lacuna] and a transport strategy register are to be filled in within the scope of an input dialogue. On this basis, a search algorithm determines the appropriate connecting block and the transport day assignment and thus brings about the precondition for loading the current travel strategy. Transport days with a travel strategy which is of equal value for reasons of operation and transport require common indicators. After the starting setting has been carried out, the respective current strategic information relating to travel is loaded under the control of the travel indicators appended to the information. The strategic information relating to travel exists in the form of blocks which each apply for a region of the travel route with a constant maximum speed. They include the functional relationship between the travel time in such a region and the switch-over points between the travel mode phases of drive and coasting or drive, normal travel and coasting, the permissible maximum speed, the length of travel for which this maximum speed applies and coding for the designation of the destination. This data sufficiently characterizes a type of train and a type of route. The strategic information relating to operation is also organized in the form of blocks and contains the type of optimum predefined value for the travel time, the time during which a vehicle stops at a station and a factor for the travel time-dependent characterization of the energy expended on each route section. For a current operating and travel strategy, the respectively required blocks are selected and connected according to a fixed assignment rule. In accordance with the requirements, any desired combination between types of train and types of timetable can thus be implemented. The blocks which are assigned to route sections are arranged in series in the train travel magazine in the order in which they are required in the course of the train journey. Here,

there is a basic block for the respective first speed range of the journey between two stops and following blocks for further adjoining speed blocks. For the sake of economy of memory space, a distinction is made between "complete following blocks" for regions above a speed specification ($V_{[illegible]}$) which is conditioned by the traffic system and "reduced following blocks" for regions with low speeds. The basic block corresponds in design and structure to a complete following block which is supplemented by the destination point code.

The information on the operating and travel strategy also contains defined marks for identifying the speed region lying directly ahead.

These identifications are executed by means of special filters processes tailored to the structure of the information. The reduction of the technical and financial expenditure, associated with this further refinement of the method, for automated train control also does not eliminate the described disadvantage.

Object of the invention

The object of the invention is to achieve further savings in energy.

Description of the essential features of the invention

The cause of the increased expenditure of energy, which cannot be utilized to ensure or restore punctuality in certain situations in transport operations (delays of the means of transportation traveling ahead) is the fact that starting data acquired from the travel situation of the means of transportation under consideration are used for determining and predefining the control strategy, and in this context essentially the current travel time reserve up to the scheduled time of arrival at the next stop.

The technical object of the invention consists in providing a means of transportation which is traveling ahead but whose compliance with the timetable has been disrupted with a control strategy which affords the described additional expenditure by taking into account the effects of said means of transportation.

According to the invention, the method consists in the fact that when a means of transportation is delayed, data relating to the remaining time difference up to the expiry of the decisive time of succession of trains is transmitted to the following means of transportation which is using the same transport route. In the simplest case, and under the conditions of the circulation of similar means of transportation, as is normally the case with municipal express trains, the means of transportation which is moving off from a stop actuates a backward-running time measuring operation by means of track switching means, the starting value of which time measuring operation corresponds to the decisive time of succession of trains which is valid for the route section lying ahead. This time measuring operation which can be viewed by the driver of the following vehicle stops when the value "0" is reached, but at the earliest at the moment when the following means of transportation moves off and thus indicates the time supplement which is to be input manually by the driver of said means of transportation into the electronic control there. This control device evaluates this supplement additively with respect to the automatically determined travel time margin (travel time up to the next stop which is determined by the individual means of transportation itself in order to become successively more punctual with minimum additional expenditure of energy) in order then to determine in a known way a new travel strategy with optimum energy consumption using the control device. The new travel time is determined in such a way that

the means of transportation passes all the subsequent signals up to the next stop without disruption by safety equipment and in the process aims at punctuality as it travels in the same degree as the means of transportation traveling ahead:

One refinement of the invention consists in the fact that the time measuring device inputs the time supplement as wireless information (data telegram) into the control device of the following means of transportation and thus relieves the driver of the vehicle of the need to make manual inputs.

A further refinement of the invention consists in the fact that the time measuring device can be actuated by a means of transportation which moves on another route if this other route has a junction with or is in contact with the route traveled on by the means of transportation in question, before the next stop of said means of transportation, this means of transportation being a following means of transportation only after the junction point, and therefore being the second means of transportation to pass this point.

Finally, the method can also be embodied in such a way that the control devices of the means of transportation which is traveling ahead on the same route or on the route which has a junction with said route or is in contact with it communicates with the following means of transportation directly or via an operations control center in that the control device of the means of transportation traveling ahead activates an internal time measuring operation in the control device of the following means of transportation and said time measuring operation obtains its starting value from the stored data of the route section to be traveled along. This requires the time of succession of trains of each

route section to be a component of the storage volume of the control device.

Exemplary embodiment

The invention will be explained below in more detail with reference to an example.

For a route section between two stops there is a decisive time of succession of trains t_{Zm} which is formed from the division of this route section, in terms of safety equipment, into block sections, the scheduled travel speeds of the means of transport on the block sections, the technological and technical time portions for the opening of a block section in such a way that its previous blockage is just such that it no longer influences the mode of travel of the following means of transportation, and forms other elements.

This time can be longer than the time of succession of trains t_Z at the starting point of the route section, i.e. a following means of transportation can move off in terms of safety equipment but inevitably comes up against a signal blocking onward travel when it reaches the end point. This will occur in particular if the following means of transportation is also delayed and its control device consequently predefines a mode of travel which is directed at restoring punctuality. The means of transportation traveling ahead activates, at the moment it moves off, a backward-counting time measuring device which counts in seconds and which can be viewed by the driver of the following means of transportation or can communicate with the control device of the following means of transportation, while in another variant the time measuring device is located within this control device and the means of transportation therefore communicate with one another directly or via an operations control center.

In another basic variant, the aforesaid time measuring device can be triggered, in each of the three solution variants, by the control device of a means of transportation which is not located on the same route, if its route joins that of the following means of transportation, or is in contact with it, this means of transportation therefore becoming a following means of transportation only after the junction, and therefore being the second means of transportation to pass this point.

The starting value of the time measuring device corresponds to the number of seconds of the time of succession of trains l_{zm} which is decisive for the route section. The time measuring device stops at the moment when the following means of transportation moves off and indicates a residual value of the aforesaid time of succession of trains l_{zmr} which is smaller than the starting value t_{zm}. The travel time margin t_{FV}, determined internally by the control device, up to the scheduled time when the means of transportation stops at the next stop, must be increased by this value. The modified travel time is then consequently t_{FV} + $l_{am[illegible]}$.

This is carried out by a manual inputting procedure by the driver or communicatively as a data telegram from a fixed time measuring device of the [lacuna] from means of transportation to means of transportation, if appropriate via an operations control center without interaction of the driver of the means of transportation in the control device. The mode of travel which is determined by the control device is thus based on a longer travel time and is consequently less energy-intensive. Because it also ensures that renewed stopping is avoided at the next scheduled stop, a double energetic effect is obtained. The delay is

thus reduced only to the same degree as that of the vehicle traveling ahead.

Patent claims

1. A method for the energy-saving control of rail-bound means of transportation which travel in succession, each of which means of transportation is controlled individually in an optimum way with respect to energy, characterized in that when a means of transportation is delayed, data on the remaining time difference up to the expiry of the decisive time of the succession of trains is transmitted to the following means of transportation which uses the same transport route, in that, in the simplest case and under the conditions of the circulation of similar means of transportation, as is usually the case in municipal express trains, means of transportation which move off from a stop activate a backward-running time measuring operation by means of track-switching means, the initial value of which time measuring operation corresponds to the decisive time of succession of trains which is valid for the route section lying ahead, and in that this time measuring operation which can be viewed by the driver of the following vehicle stops when the value "0" is reached, but at the earliest at the moment when the following means of transportation moves off, and thus indicates the time supplement which is to be input manually by the driver of said means of transportation into the electronic controller and is evaluated additively with respect to the automatically determined travel time margin (travel time, determined by the individual means of transportation for itself, up to the next stop in order to be successively more punctual with the least degree of expenditure of energy) by this control device as a supplement so that a new travel strategy can then be determined in a known fashion with optimum consumption of energy using the control device, the new travel time being determined such that the means of transportation passes through the signals as far as the next stop without being impeded in terms of signaling equipment

and aims at punctuality as it travels to the same degree as the means of transportation traveling ahead.

2. The method as claimed in claim 1, characterized in that the time measuring device inputs the time supplement as wireless information (data telegram) into the control device of the following means of transportation.

3. The method as claimed in claim 1 or 2, characterized in that the time measuring device can be actuated by a means of transportation which moves on another route if this other route has a junction with or is in contact with the route traveled on by the means of transportation in question, before the next stop of said means of transportation, this means of transportation being a following means of transportation only after the junction point, and therefore being the second means of transportation to pass this point.

4. The method as claimed in claim 1 or 3, characterized in that the control device of the means of transportation which is traveling ahead on the same route or on the route which has a junction with said route or is in contact with it communicates with the following means of transportation directly or via an operations control center in that the latter activates an internal time measuring operation in the control device of the following means of transportation and said time measuring operation obtains its starting value from its memory, in which memory the decisive times of succession of trains are stored together with the other characterizing data of each individual route section.